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**Solar Flares and Magnetospheric Particles:  
Investigations Based Upon the ONR-602  
AD-A281 463 and ONR-604 Experiments**



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**Performance Report**

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## **"Solar Flares and Magnetospheric Particles: Investigations Based Upon the ONR-602 and ONR-604 Experiments"**

### **I. Introduction:**

This performance report covers work accomplished under ONR Grant N00014-90-J-1466 related to the radiation environment in near-Earth space. The goal of the research is to measure and describe, quantitatively, the Geospace radiation environment in which men and spacecraft must survive and function. The tools for this investigation are the data returned by the ONR-602 and ONR-604 experiments, both flown under the auspices of ONR and the Air Force Space Test Program, augmented by correlative databases of both space-based and ground-based data. The investigation involves data analysis, modeling and applications to a variety of space equipment and environments.

This report builds upon the detailed Technical Report (Fall, 1992) and the previous performance reports. For the current period, the principal effort was in further analysis of quiet-time particle access to the inner magnetosphere and in expanded solar energetic particle investigations.

### **II. Helium in the Inner Magnetosphere**

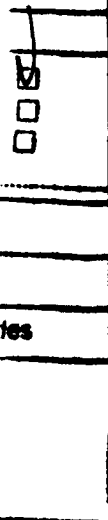
In the previous report, we described observations of trapped or quasi-trapped helium at energies of ~45-100 MeV/nucleon. As shown in Figure 1, these particles are located around  $L=2$  and around  $L=1.2$ . The vast majority of the helium is observed at  $L\sim 6-7$  and is from the Galactic Cosmic Rays (GCR). (Note only solar quiet periods are included, so that we are not "contaminated" with any solar energetic particle events.) The GCR flux declines rapidly with  $L$  shell and cannot be the direct cause of the distinct bands observed at  $L<2.3$ . Note also that there is a difference in the energy distribution of the helium around  $L=2$  and  $L=1.2$ . We will return to this point later.

CRRES is in an  $18^\circ$  inclination orbit which varies in altitude from ~350 km near perigee to almost geosynchronous altitude at apogee. It does not pass through the heart of the South Atlantic Anomaly, but does sample the earth's radiation belts at different altitudes. Therefore, we have looked at the altitude (above earth's surface) versus  $L$  distribution for all of the events at  $L<3$  in Figure 1. The result is shown in Figure 2. Note that the  $L\sim 1.2$  peak is located at relatively low altitudes as might be expected from a precipitating particle population. The  $L\sim 2$  events, however, cluster between 4000 and 8000 km and are well separated from the  $L\sim 1.2$  group. This could indicate observation at the edge of the inner proton radiation belt.

We have also searched for a clustering in longitude for the low- $L$  events. There seems to be none. Within the limited statistics, the events appear to be about uniformly distributed in longitude which may reflect merely the precession of the orbit of the CRRES spacecraft.

It has been suggested that the helium may be singly charged, from either the anomalous component or from solar energetic particle (SEP) events. In a simple dipole model of the Earth's field, it is straightforward to calculate the rigidity a particle must have to penetrate to a given location. This is called the Directional Dipole cut-off. For each helium event, we can calculate this cut-off for both the case of doubly charged and singly charged helium. Such calculations are compared to the measured incident energies (outside the instrument) in Figure 3. The lines separating allowed (to the left) from non-allowed (to the right) particles are indicated for both assumptions about the charge state of the helium. Note that the majority of the helium is allowed,

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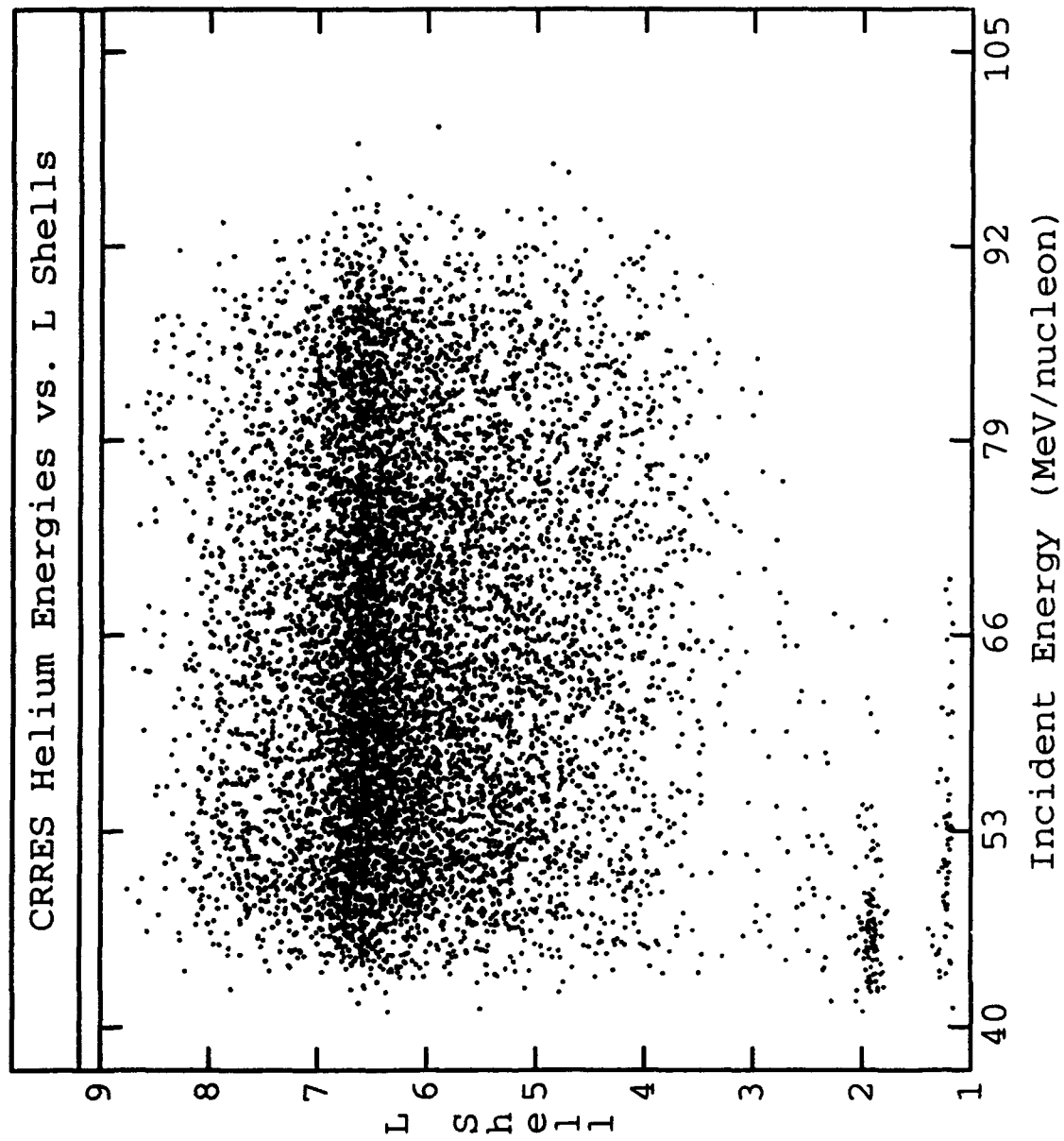


Figure 1. L-shell versus incident kinetic energy for all solar quiet-time helium events.

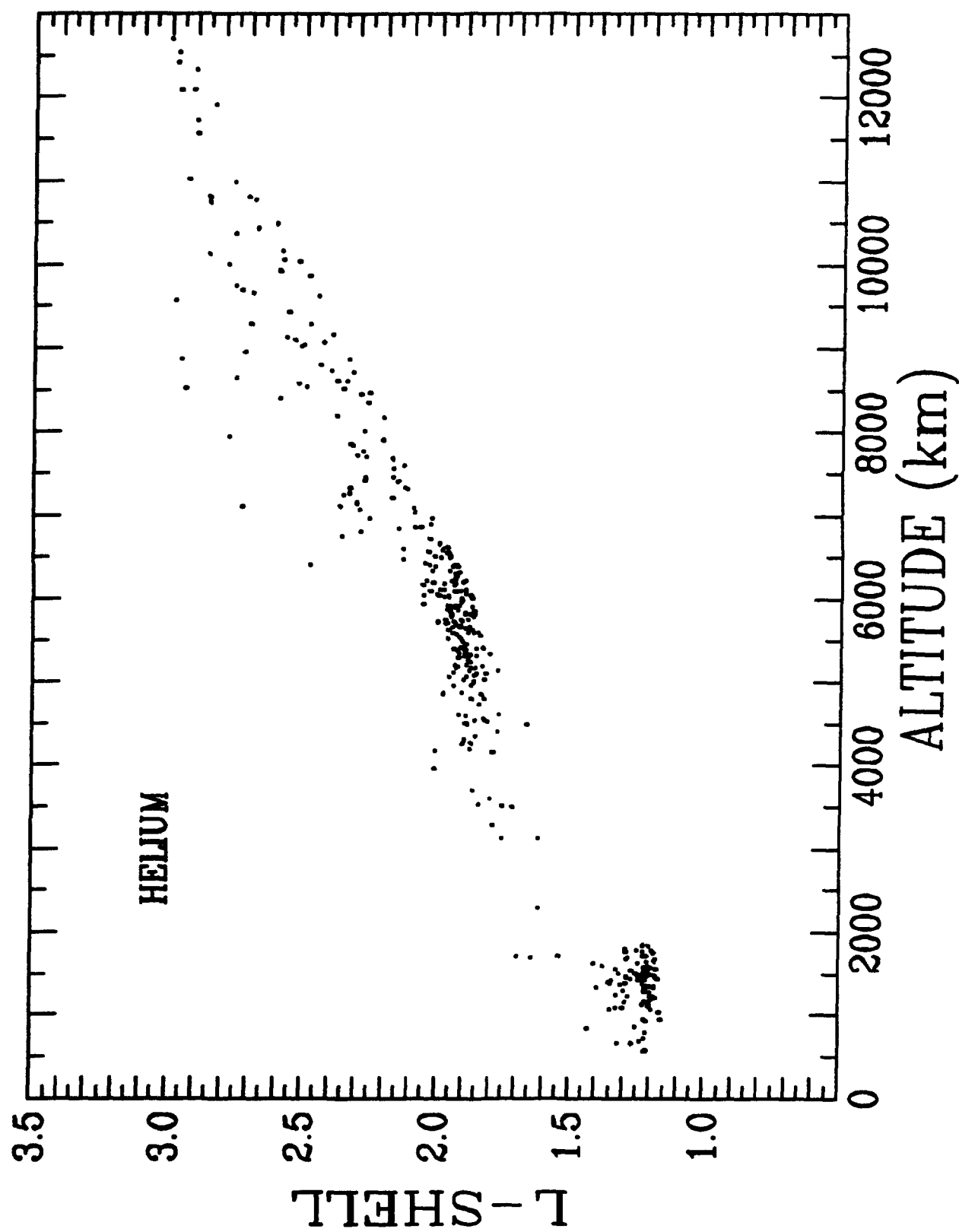


Figure 2. L-shell versus altitude for helium with  $L < 3$ .

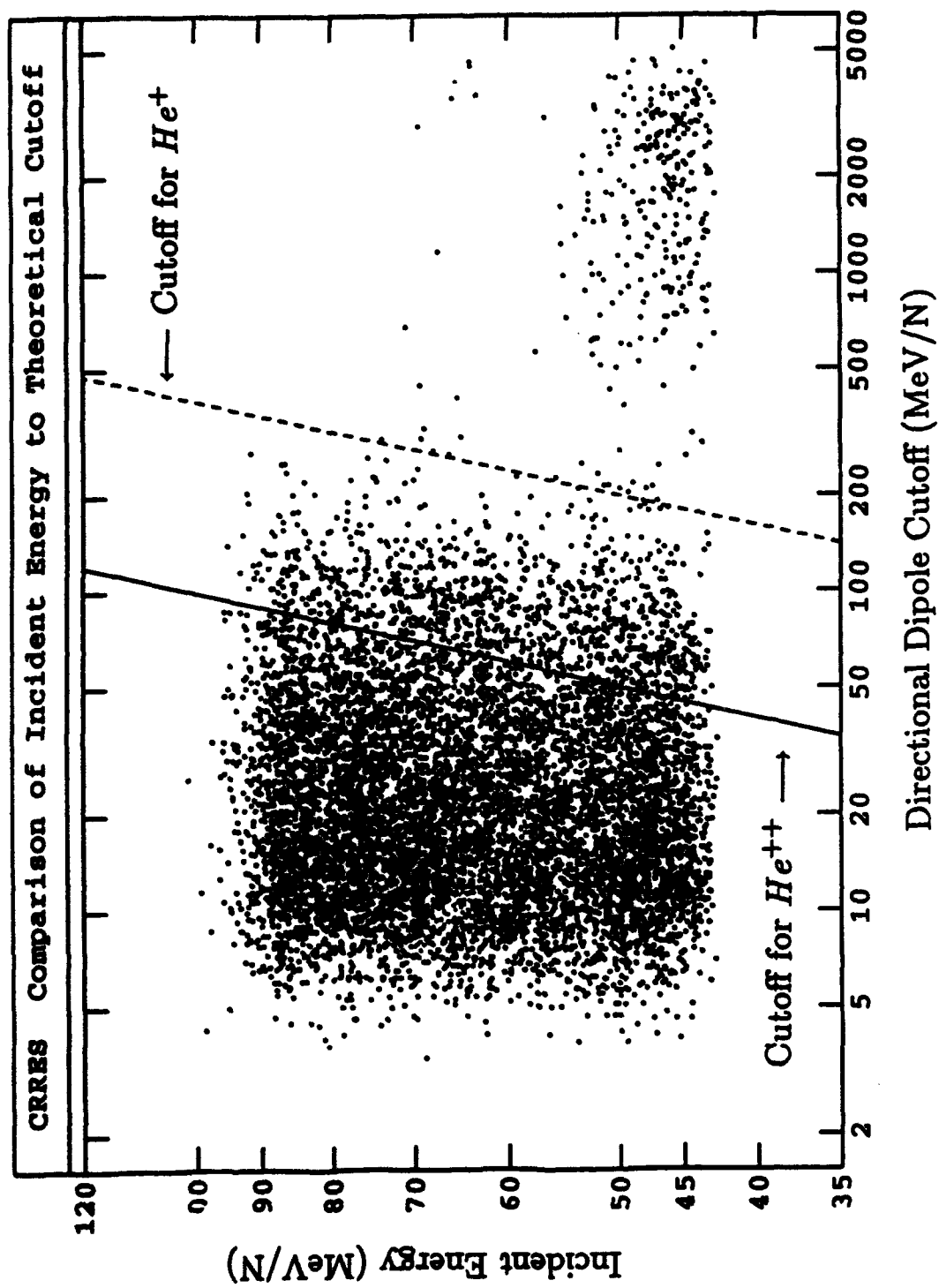


Figure 3. Directional Dipole Cut-offs (MeV/nucleon) versus incident particle energy (MeV/nucleon) for quiet-time helium events.

doubly charged GCR events as expected. The events extending to the right of the  $\text{He}^{++}$  line and still to the left of the  $\text{He}^+$  line are candidates for singly charged particles. However, the dipole approximation is not a fully accurate representation of the earth's magnetic field, and before concluding that there is a tail of singly charged helium among the otherwise galactic distribution, a full particle tracing simulation, in an accurate field model, must be performed. Such tracing has been done for a few selected events, and, in general, there is little evidence for singly charged helium in the overall GCR dataset.

The important point about Figure 3 is the group of events to the far right. These are the low-L events and should not be there if direct penetration of singly-charged helium is involved. Tracing calculations verify this conclusion, as might be expected. A Directional Dipole Cutoff of  $>500$  MeV/nucleon for a particle observed at 40-50 MeV/nucleon is a problem for direct penetration. Note also that the events on the right do not extend to the full 100 MeV/nucleon as do the GCR's on the left side. The "trapped" helium is concentrated at  $\sim 45$ -70 MeV/nucleon.

To investigate the energy distribution in more detail, we have computed the flux (assuming omni-directionality) for the helium in the L $\sim$ 2 peak. The data was divided into two sections, before and after the large event of 3/24/91. Note that, as discussed in the last report, the number of events at L $\sim$ 2 decreased markedly after the March storm. The energy spectrum observed is shown in Figure 4 plotted in total energy, i.e. four times the kinetic energy per nucleon. Also shown is earlier data of Rubin et al. (1977) who measured lower energy trapped helium ( $E < 18$  MeV/nucleon). Both datasets are well fit by a power-law energy spectrum, which, for Rubin et al., has been extended into the CRRES energy range.

For the pre-storm period, CRRES finds a power-law spectrum with an index of  $10 \pm 0.7$  much softer than the Rubin et al. index of  $5.5 \pm 1.3$  measured in the region  $1.85 \leq L \leq 2.65$ , roughly the same as the CRRES L range. After the March storm, CRRES finds essentially the same soft spectrum but at nearly an order of magnitude reduced intensity. The CRRES flux, extrapolated to the low energies measured by Rubin et al. would be orders of magnitude larger than the result shown in Figure 4. Thus, it is not clear whether these two experiments are measuring the same trapped population or, if they are, whether the discrepancy is a temporal effect or a geometric acceptance difference between the two instruments. Further work will be required to understand this issue quantitatively.

In the L $\sim$ 1.2 region, we find a spectral index of  $6.8 \pm 1.0$ , consistent with the Rubin et al. result, but in a different L range! This extrapolated flux is still about a factor of 10 above the earlier result of Rubin et al.

What is of most importance here is the observation of high energy trapped (or pseudo-trapped) helium deep within the magnetosphere. This could be of importance for the SEU problem and for spacecraft survivability even though the flux of such particles is small. Although the origin of this helium is not well understood, the observations are of sufficient importance, we believe, that they should be submitted for publication. This will be one of our tasks for the next quarter.

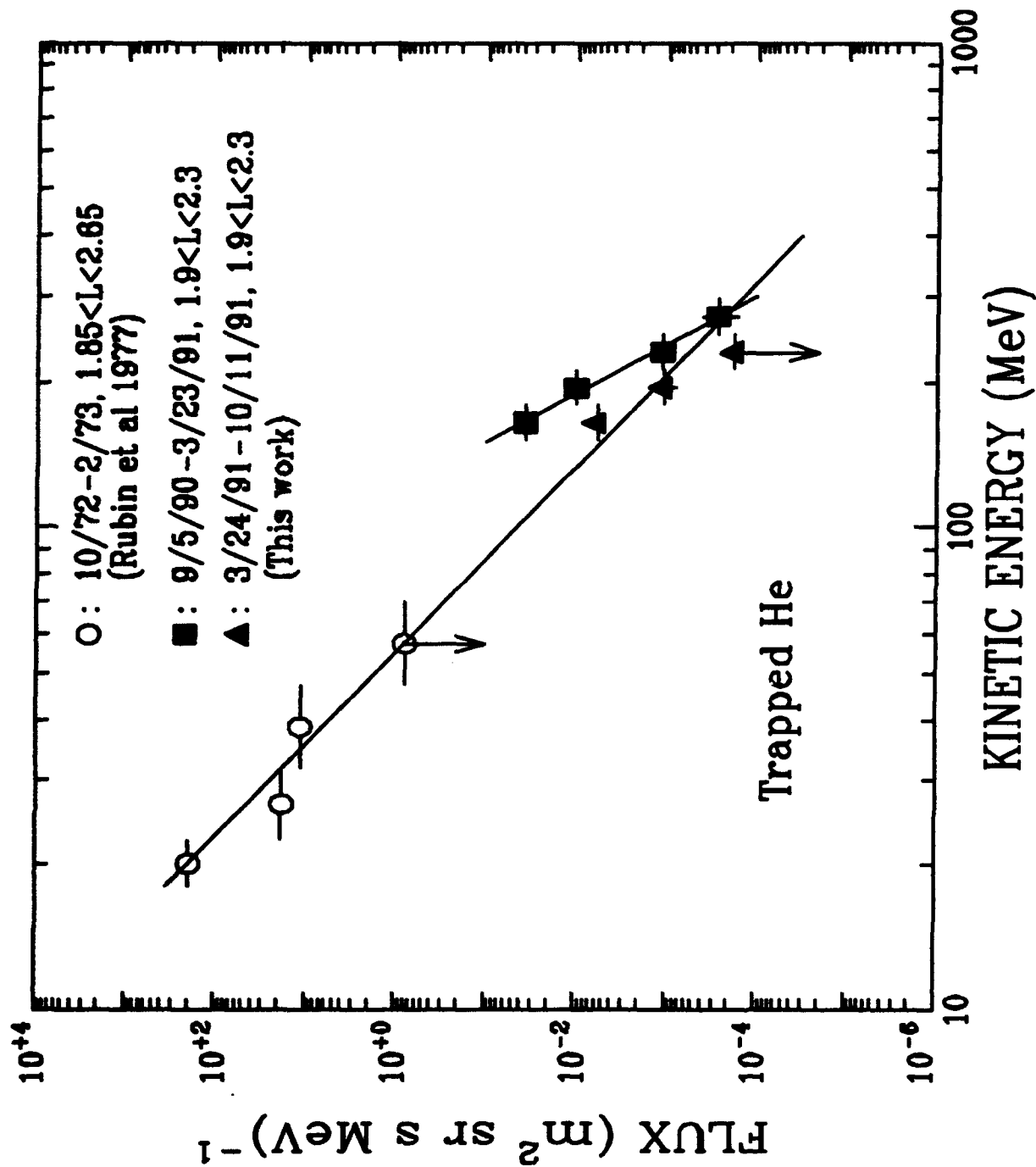


Figure 4. Energy spectra of the L-2 trapped helium before and after the March, 1991 substorm compared to previous observations at lower energies.

### III. Solar Energetic Particles

Previously we described work on the large solar flares observed during the CRRES mission. This involved measuring spectra of helium and protons and estimating the heavy ion enrichment, if any, in the flare. These large SEP events are the most important, but a full description of the environment during the CRRES mission involves the smaller flares as well. We have begun an analysis of all the SEP events that can be identified from the ONR-604 data. Twenty-six (26) separate events have been isolated as given in Table 1. Work is proceeding to analyze each flare as fully as possible, and completing this job will be one of our main tasks for the next quarter.

**TABLE 1.** SEP Events During the CRRES Mission

Event Number	Peak Orbit	Start (Day)	Peak (Day)	End (Day)	Peak He (cnt/orb)	Assoc. Flare (Day/UT)	Imp. X-ray/ $H_{\alpha}$	Location	Region Number
1	-	207.7/90	208.0	209.5/90	-	-	-	-	-
2	-	213.0/90	213.8	214.9/90	-	Jul30/0736	M4/2B	N20E45	6180
3	218	296.5/90	296.7	297.6/90	43	-	-	-	-
4	451	26.0/91	27.2	29.3/91	201	Jan25/0630	X10/SF	S16E78	6471
5	462	31.3	31.7	32.4	481	Jan31/0230	X1/2B	S17W35	6469
6	481	39.3	39.6	39.9	53	Feb07/1502	M8/1F	S10W86	6471
7	522	56.4	56.5	57.6	235	Feb25/0819	X1/2N	S16W80	6497
8	548	66.4	66.9	67.2	72	Mar07/0748	X5/3B	S20E66	6538
9	562	72.0	72.7	73.0	39	Mar12/1250	X1/2B	S07E59	6545
10	587	82.1	83.1	84.6	9026	Mar22/2247	X9/3B	S26E28	6555
11	593	84.6	85.4	87.6	3234	Mar25/0818	X5/3B	S24W13	6555
12	613	93.0	93.6	94.5	60	Apr02/2327	M6/3B	N14W00	6562
13	655	110.5	110.8	111.2	75	Apr20/0852	X1/3N	N08W50	6583
14	684	122.1	122.6	123.1	46	-	-	-	-
15	704	130.7	130.9	131.7	78	-	-	-	-
16	710	133.1	133.4	135.0	517	May13/0144	M8/-	S09W90	6615
17	730	139.0	141.5	142.9	63	May18/0546	X2/2B	N32W85	6619
18	756	151.2	152.2	153.0	91	May30/0938	M8/1B	N07E30	6654
19	774	153.0	159.6	162.1	23404	Jun04/0352*	X12/3B	N30E70	6659
20	781	162.1	162.6	165.5	13236	Jun11/0209	X12/3B	N31W17	6659
21	791	166.3	166.7	173.6	10101	Jun15/0821	X12/3B	N33W69	6659
22	829	179.5	183.0	188.3	1648	Jun28/0626	M6/-	N30E85	6703
23	843	188.4	189.1	190.3	370	Jul07/0223	X1/2B	N26E03	6703
24	942	231.1	231.5	231.9	45	-	-	-	-
25	961	238.7	239.7	241.4	156	Aug25/0115	X2/2B	N25E64	6810
26	1040	273.0	273.7	276.3	212	Sep29/1533	M7/4B	S21E32	6853

\* Event 19 may associate three solar flares peaked at Jun1/1529 (X12/1F, N25E90), Jun4/0352 (X12/3B, N30E70), and Jun6/0112 (X12/4B, N33E44) in the same NOAA region 6659. The source for the flare identification (columns 7, 8, 9, and 10) is from Solar-Geophysical Data books (1991).